

Coastal Aerosol Study, Duck North Carolina, ONR (CASCO)

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Grant Number: N00014-96-1-0581

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LONG TERM GOALS

The long-term goals of the research are to understand and assess the effects of the atmosphere on the detection of targets at low altitudes over sea in coastal regions with LR-IRST systems. Effects considered are transmission losses due to aerosols and water vapor, effects of turbulent fluctuations of the air temperature on blurring and scintillation, and the effect of the vertical temperature gradients on IR refractivity.

OBJECTIVES

The objectives of the research performed in the framework of the present grant are to further analyze and validate results obtained in the EOPACE experiments, in particular:

- to validate the aerosol source function in the surf zone;
- to quantify the effect of the surf zone on the aerosol concentrations in the coastal atmosphere, in relation to surface-produced sea spray aerosol and anthropogenic aerosol;
- to determine the turbulence and refractivity in the inhomogeneous coastal boundary layer and their effects on imaging of low altitude point targets;
- to improve the description of the aerosol size distribution as function of height and meteorological parameters.

APPROACH

Data from the EOPACE IOP's (1-9) in 1996-1999 are further analyzed and interpreted.

During the EOPACE experiments in Duck, North Carolina, aerosol particle size distributions were measured at three levels at the base of the pier. From comparison with particle size distributions measured at the end of the pier by the group of Prof. Mike Smith from the University of Sunderland (UK), surf-aerosol source functions will be derived. The results will be compared with those obtained at the Californian coast. In addition, lidar measurements were made on the aerosol plumes generated by waves breaking in the surf zone.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE SEP 2000		2. REPORT TYPE		3. DATES COVERED 00-00-2000 to 00-00-2000	
4. TITLE AND SUBTITLE Coastal Aerosol Study, Duck North Carolina, ONR (CASCO)				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) TNO Physics and Electronics Laboratory,,P.O. Box 96864,2509 JG The Hague,,The Netherlands, ,				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 12	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Furthermore, a boat was equipped with optical particle counters, a sonic, a lidar system and meteorological instrumentation to obtain data on the evolution of the aerosol size distributions and the coastal atmospheric boundary layer in off-shore winds. The goals were to study coastal aerosol transport and to validate the Coastal Aerosol Transport model (CAT) which was specifically developed, by Dr. Vignati (current affiliation Joint research Center, Ispra, Italy), to determine the effects of surf-produced aerosol.

The boat was further equipped with infra-red sources to derive atmospheric propagation properties such as transmission, scintillation and refraction, as function of fetch, from data collected with thermal imagers by Ir. De Jong (TNO-FEL) and other EOPACE participants.

WORK COMPLETED

- The analysis of the surf aerosol data obtained at the Californian coast has been completed. The results are presented in De Leeuw et al. [2000a].
- The analysis of the Duck aerosol and lidar data will be completed in FY01. A publication is in preparation.
- The Coastal Aerosol Model CAT has been further developed. CAT was used for the analysis of the effects of surf aerosol. The results are presented in a paper submitted to JGR (September 2000) [Vignati et al., 2001]
- The aerosol data for IOP3, IOP4 and IOP7 has been continued in connection with the analysis of transmission measurements over Monterey bay (22 km) and San Diego Bay (7 and 15 km). Results have been transferred to Dr. Zeisse from SSC San Diego, for inclusion in a common publication [Zeisse et al., 2001].
- Contributions to an EOPACE overview paper [Jensen et al., 2001].
- Several proceedings papers were produced in connection with presentations at scientific conferences (see listing in 'Publications').

RESULTS

The data obtained from the lidar, the aerosol measurements, and the turbulence measurements (boat only) during the Duck 1999 experiments, including both measurements from the boat and from the base of the Duck Pier, have been partly analyzed. Unfortunately, the boat could sail only in relatively calm weather. As a result, data were obtained for only four days, none of which was suitable for testing the Coastal Aerosol Model CAT. The data are described in Moerman et al. [2000], where examples are presented of lidar scans and vertical structure, comparisons between lidar-derived backscatter and backscatter calculated from simultaneously measured aerosol size distributions using the TNO Mie code. Also data are presented showing the variation of the aerosol concentrations and meteorological parameters with time, and for various positions along the boat track. The boat sailed out to fetches of 25 km. The fetch dependence is not a true representation of horizontal variability, since the various

samples were collected consecutively at changing fetches, and thus not at the same time. Also, no attempts were made to make Lagrangian experiments.

In Moerman et al. [2000], also results are presented from lidar measurements over the surf zone from the base of Duck pier. An example is presented in Figure 1. The lidar clearly shows the aerosol plumes and their evolution in time and in space.

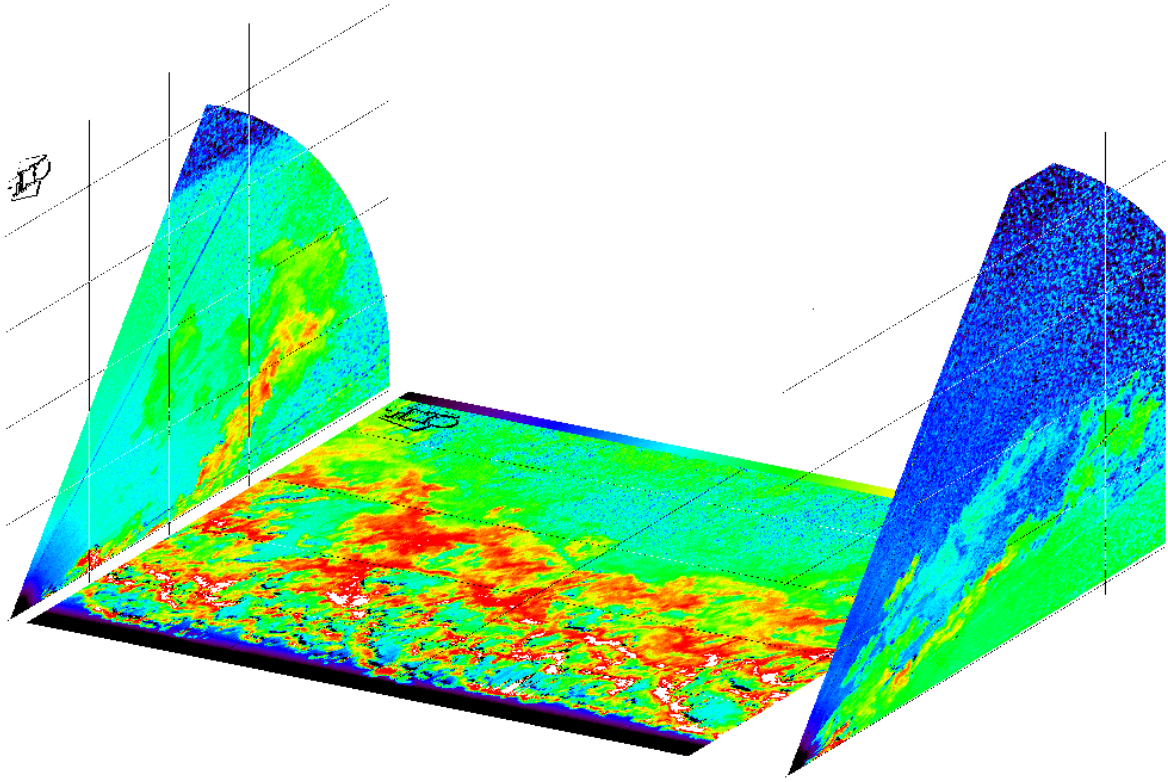


Figure 1. Quasi-3D compilation of the atmospheric backscatter coefficient over the surf zone. The horizontal plane shows 240 seconds of consecutive measurements with the lidar fixed in a horizontal direction parallel with the pier. The left vertical scan was made consecutively (15:00 UTC), the right scan was made 4 hours later (19:00 UTC). The maximum range shown is 1.2 km and the maximum scan height is about 1.0 km. The backscatter scale ranges from $\log[1.0 \cdot 10^{-7} \text{ (m.sr)}^{-1}]$ (black) to $\log[1.0 \cdot 10^{-5} \text{ (m.sr)}^{-1}]$ (white). Source: Kunz et al. [2000].

Quantitative results of the lidar backscatter over the surf were compared with aerosol data obtained from optical particle counters installed over the surf zone close to the landward edge, at three levels. In general the results compare favorably, taking into account that the lidar provides a snapshot, whereas the aerosol data are usually averages over time lapses of typically 10 minutes or longer. Averages were obtained from a number of lidar scans. In an inhomogeneously distributed aerosol such as encountered over the surf zone (cf. Figure 1) such averages are likely not representative for a true mean value.

The Duck surf aerosol measurements have been partly analyzed. So far, no clear result have been obtained and the structure observed over the Californian coast has not yet been confirmed. In part this is due to insufficient ‘background’ correction, which will be done properly when data are available from the end of the pier. On the other hand, also there was no clear wind regime during Duck, and the mostly along-shore transport of the aerosols may have resulted in much better mixing than in the clear on/off-shore winds caused by the land-sea breezes encountered in California.

The effects of surf produced aerosol has been analyzed using the coastal aerosol model CAT. Several modifications had to be introduced in the model, such as the effects of atmospheric stability and a sea spray source function that accounts for the production of particles down to $0.07 \mu\text{m}$. Current source functions were not suitable, as deduced from comparison with the few available experimental data. The derived model applies only for wind speed of 9 ms^{-1} . A comparison with the source functions formulations by Monahan et al. [1986] (M86) and Smith et al. [1993] (S93) is shown in Figure 2. Also shown is a comparison of the particle size distribution resulting from using the three models, and a comparison with data from O’Dowd et al. [1997] (OD97).

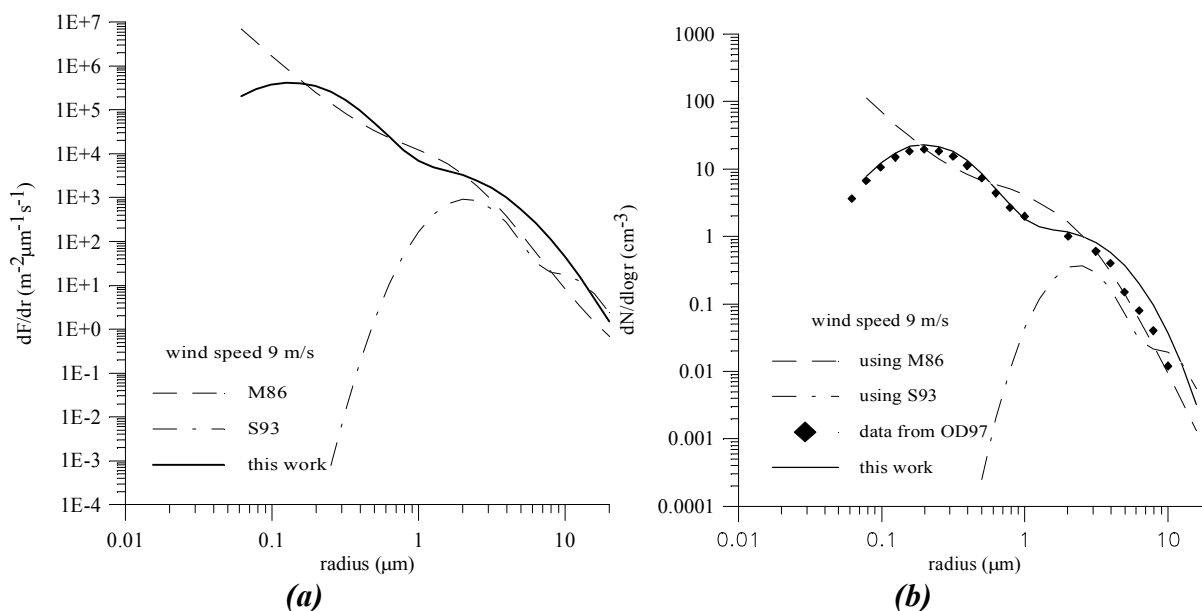


Figure 2. a) Sea spray aerosol source functions dF/dr , as function of radius, for wind speed of 9 ms^{-1} . b) Comparison of modelled particle size distributions with data from O’Dowd et al. (1997) for a wind speed of 9 ms^{-1} . The data were calculated with different source functions. Source: Vignati et al. [2001].

CAT has been tested with several independent data sets, and was subsequently used in studies on the impact of surf aerosol as regards the evolution of the aerosol plume produced over the surf zone (comparison was made with lidar measurements), aerosol vertical profiles and aerosol composition (i.e. the ratio of continental and marine aerosol), and the effect of sea spray on profiles of nitric acid. Results are presented in Vignati et al. [2001].

During EOPACE experiments in 1996 and 1997, transmission was measured across San Diego Bay, along an over-water path of 15 km by TNO-FEL and over a 7 km path by Dr. Zeisse from SPAWAR (San Diego), with meteorological data collected at mid-path by Professor Davidson from NPS (Monterey). TNO-FEL also measured aerosol particle size distributions at the end of the 15 km path. The data are analyzed in a common effort with SPAWAR and NPS. An example of the results is shown in Figure 3, where the transmission along the 15 km path calculated from measured aerosol size distributions combined with MODTRAN calculations of molecular effects, using simultaneously measured meteorological parameters, is compared with the measured transmission, both for the 3.55-4.1 μm wavelength band. The transmission data show daily variations that are ascribed to the sea breeze effect. In off-shore wind the transmission is much higher than in on-shore wind, due to contributions from the surf-produced aerosol in off-shore wind. Aerosols are a governing but often quite uncertain factor for transmission in the coastal environment. Current models do not account for the large variability of the aerosol concentrations in the coastal zone. Residual transmission effects are strongly correlated with thermal stratification in the atmospheric surface layer, indicating the importance of refraction.

The ratio of the measured transmission and the calculated total transmission in Figure 4a shows that discrepancies of a factor 10 may occur at times. Also shown in Figure 4a is the air-sea temperature difference (ASTD), a crude indication for atmospheric stability. The transmission ratio and the ASTD seem to be anti-correlated, which is confirmed by the scatter plot in Figure 4b. This is a strong indication for the effect of refraction: for a positive ASTD, when the air is warmer than the water, light rays curve toward the surface. *Vice versa*, when the air is colder than the water, the light beam curves away from the Earth's surface. For a non-linear temperature gradient, this may lead to atmospheric focussing or de-focussing, i.e. enhancement or reduction of the transmitted light intensity.

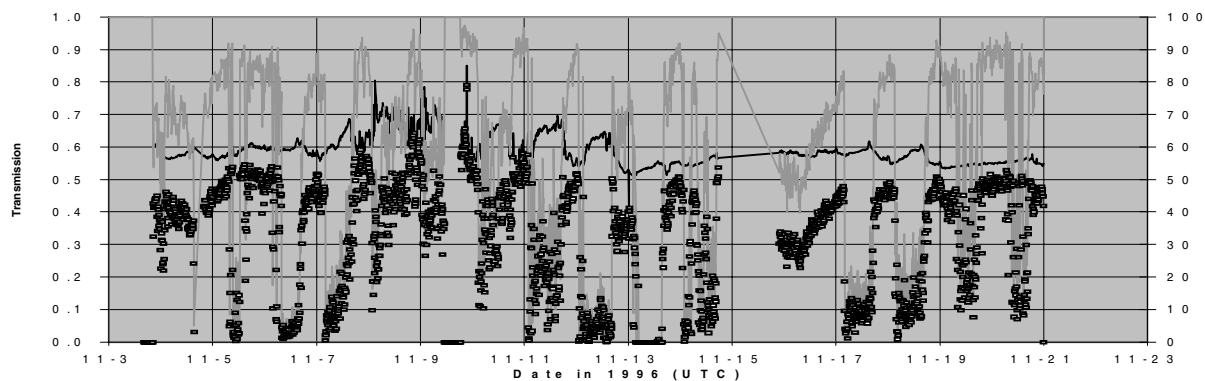


Figure 3. Transmission for a wavelength of 4 μm measured along a 15 km path across San Diego Bay during the EOPACE experiments in November 1996 (dots). The dark line is the MODTRAN calculated transmission and the grey line is the transmission derived from the aerosol particle size distributions. Source: De Leeuw et al. [2000b].

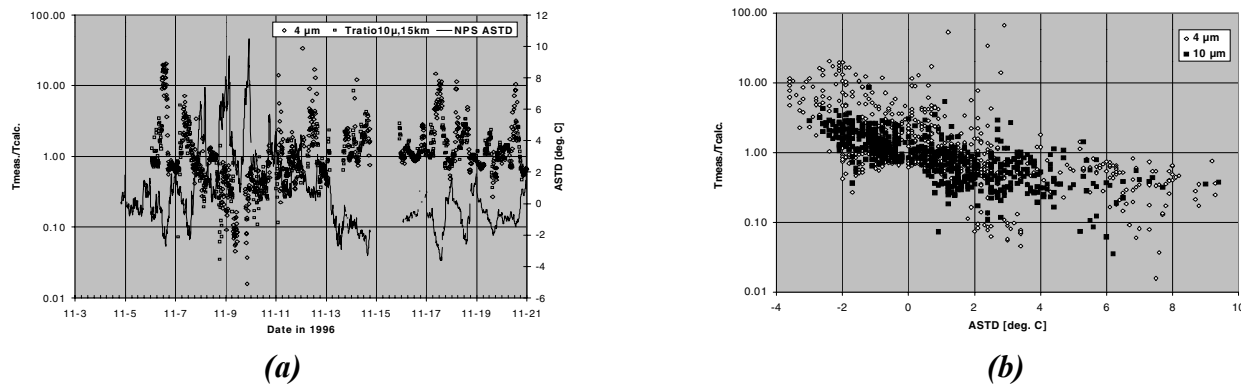


Figure 4. a) Ratio of measured and calculated transmission for wavelengths of 4 (\diamond) and 10.6 μm (\blacksquare). The line presents the air-sea temperature difference (ASTD, in $^{\circ}\text{C}$) measured in the middle of the over-water propagation path. b) Ratio of measured and calculated transmission plotted versus the ASTD. Source: De Leeuw et al. [2000b].

IMPACT

The results can be used to assess the effects of the atmosphere on the performance of thermal imagers over sea, and in particular the performance of LR-IRST systems. The surf-produced aerosol affects atmospheric processes involving sea spray particles, such as heterogeneous reactions, at fetches of at least 10 km in off-shore winds. Reaction between sea spray and HNO_3 has consequences for atmospheric inputs of nitrogen compounds in coastal waters, and thus eutrophication [De Leeuw et al., 2001; Sorensen et al., 2001]. Over land, sea spray influence fragile coastal eco-systems, and the corrosive properties cause damage to buildings, structures and cultural heritage.

TRANSITIONS

The EOPACE results of TNO-FEL are exchanged with other EOPACE participants, to lead to a common analysis effort combining all required expertise to achieve the EOPACE goals. Common publications have been submitted, others are in preparation.

RELATED PROJECTS

The efforts described above are in conjunction with other projects addressing electro-optical propagation over sea, in part basic research, in part applied research. The EOPACE efforts will take place in conjunction with EOPACE studies funded by the Netherlands Ministry of Defense, including work on long-range transmission, IRST and backgrounds. Data from other areas, e.g. the North Sea, the North Atlantic, the Mediterranean and the Baltic, are from other projects supported by the Netherlands Ministry of Defense, the EU or other funding agencies.

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